SEISMIC RESISTANT IMPLICATIONS
OF 1980 GUAYAQUIL, ECUADOR EARTHQUAKE

Otton Lara (I)
Presenting Author: Otton Lara

SUMMARY

On Augusth 18th, 1980 a 5.6 Richter magnitude earthquake struck the City of Guayaquil inducing the lost of 20 human beings, and economics -- losses for more than 10 million dollars. The epicenter was located at about 36 Km from downtown Guayaquil and the depth of the fows was 56 Km as estimated by the National Observatory (1) and the United States Geological Survey (U.S.G.S.) (2). Figures 1 and 2. Unfortunally, there were no instruments functioning at the time of the earthquake, however, taking advantage of the damage observed, an attempt is made, through the appropiate studies, of obtaining some characteristics of the ground motion, as well as, the expected response of three structures, which would permit to presente some general recomendations for the improvement of the earthquake resistant design practice in the area.

OBJECTIVES AND SCOPE

First, to establish the causes of the damage observed in two Reinforced Concrete (R/C) structures. To attain this objective, analytical three-dimensional (3D) models were used to determine the dynamic characteristics of each one of the structures. Then, knowing the resistant function of the members and using the first mode approximation, the Pseudo spectral acceleration, necessary to produce the damage observed, was estimated. Second, to determine why other structures, designed according to the Ecuadorian Code (3), did not suffer any damage during the earthquake. To reach this objective, another structure, which remained undamaged, was studied through an analytical 3D model, and using the procedure, above mentioned, the Pseudo spectral acceleration than would induce damage was obtained. Third, to estimate a spectral form of the ground motion. To obtain this objective, the results of the first two objectives were used, and the first Period of the Soil underlaying most of the city was estimated. Then, after a comparisson with the spectra suggested for the Country by the Ecuadorian Code (E.C.) (3), some design recomendations are made for the area of the City of Guayaquil.

STUDY OF THE BEV BUILDING

The BEV building is a 5 story administrative building which was close to be opened to the public at the time of the earthquake. The structure-is conformed by R/C beams, columns and a 250 mm waffle type of slab. The first floor was 6000 mm longer than the other floors in the NS and EW di-

(I) Professor, Escuela Politecnica del Litoral (ESPOL).
Guayaquil, Ecuador.

rections (Fig. 3). The damage observed was in the form of cracking of the unreinforced masonary walls and horizontal cracks in the top of all perimeter columns of the first story (Photo 4).

To study this building, an analytical 3D model was obtained using the original drawings and checking all the measurements throught a survey of the building. All the structural and non-structural members were considered in this model. Since it was not possible to carry tests of the materials utilized in the construction, the materials characteristics were taken from the drawings and are" 21 N/mm^2 for the concrete and 280 N/mm^2 for the reinforcing bars. The dead load was calculated according to the weight of the structural members, as well as, that of the clay bricks used for the partitions. The live load considered was 0.25 N/mm^2 which is recomended by the E.C. (3).

The computer program ETAB (4) was utilized to determine the dynamic characteristics of this 3D model which are the periods shown in table 1 and the modes of vibration, two of which are shown in figure 5. Clearly, the torsional response would be unimportant and the building appears to be extremelly flexible since its first period is 1.0 second. This flexibility is evidenced, first, by the length of the spans: 6000 mm each; second, by the height of the stories" 4140 mm the first two stories, and 3420 mm the other three stories, and third, by the presence of the masonary in all the stories above the first, while this one was completely free of partitions.

Knowing the dynamic characteristics of the building, as well as, the yield surfaces of the structural members, which were calculated through the program INTERAC (5), a trial and error procedure was utilized in order to obtain the Pseudo-spectral acceleration that could reproduce the damage observed. After several iterations, the damage was reproduced for the NS and EW directions, independently, under a lateral force vector calculated through the first mode of vibration and a Pseudo-spectral acceleration of the order of 0.11 g. Only the first mode was used because, for each direction, the modal participation factors of the higher modes were insignificant. The way to check if the damage was reproduced, was determining the internal forces in the structural members of the structure subjected to the combination of the lateral force vector and the dead load. Later , this forces were ploted in the yield surface of the members and, if the forces were lower than those in the surface, the member was assumed to be elastic, while, if the forces were at or very near to the surface, yielding of the member was assumed. (Figs. 6, 7)

STUDY OF THE INDUSTRIAL BUILDING

The Industrial building is a high rise R/C building, 46 m. tall that was erected to satisfy two objectives: To store grains in several R/C silos in one section of it and to the process of milling those grains in another. (Fig. 8). However, the silos finish at level + 40 m. , and the building continues with R/C beams and columns at levels + 43 m. and + 46 m.

The walls that conform the silos are 200 mm R/C walls, and the rest of the structure is conformed by R/C beams and columns.

This very rigid building (Table 2), whose principal Period was 0.42 seconds, suffered damage in the beams at levels + 43 m. and + 46 m. in the form of vertical cracking in regions close to the beam-column joints.

Performing a similar method of analysis to that used for the BEV building, a maximum Pseudo-spectral acceleration of 0.08 g. was estimated as the one that could reproduce the observed damage. However, it should be mentioned that the first 3 modes contributed to the response of this building.

It is clear, from the analysis, that the torsional response of the industrial building was extremely large (Fig. 9), inducing displacements of the order of 450 mm. in the farthest corner with respect to the center of masses of the 2 top stories. This large torsional response required large deformations of the structural members and, apparently, this deformation, induced a non linear response of the beams, while the columns did not suffer any damage because the design followed the strong column-weak girder design criteria. (Fig. 10)

STUDY OF THE INDUAUTO BUILDING

INDUAUTO is a 24 story R/C office building that did not suffer any damage during the earthquake. All the building was carefully observed and there was no evidence of cracking neither to the structural members nor to the partitions. This building is conformed by R/C shear walls and R/C beams connecting them (Fig. 11), and was designed using a seismic coefficient of 0.16 g. The principal Period of the building was 2.4 seconds and the torsional response is negligible. Even more, the calculations of the modal participation factors demonstrated that only the 2 first modes were important (Table 3). Using the same procedure as in the first 2 buildings, a Pseudo-spectral acceleration of about 0.24 g. was estimated as that that could cause damage in the beams (Fig. 12). Therefore, this calculated PSa value is an upper limit of the spectral acceleration that acted upon the structure during the earthquake and, evidently, the actual PSa value should be quite lower than 0.24 g. since not even the partitions suffered damage.

ESTIMATION OF THE PERIOD OF THE SOIL

Since no studies have been done regarding the dynamic characteristics of the soil of the City of Guayaquil, it was decided to use the approach presented by Seed, et al (6) to determine the shear modulus of the soil. That is, several consolidation tests under undrained conditions were performed for the soft clayed soil of Guayaquil (7) and assuming a shear deformation of 0.01, a shear modulus of about 2.7 N/mm^2 was founded. Finally, using the One-dimensional theory of propagation of the shear wave, a Period of 1.9 seconds was estimated for the soft clay underlying the City of Guayaquil.

ESTIMATED SPECTRAL FORM

Using the information above described, an attempt is made of obtaining a spectral form of the 1980 Guayaquil earthquake. The values obtained are (1) a Pseudo-spectral acceleration (PSa) of 0.08 g. for the 0.42-seconds structure and (2) a PSa of 0.11 g. for the 1 second structure. Since the PSa should decrease with decreasing Period, it is reasonable to expect a descendent branch of the spectra begining in the vecinity of 0.4 seconds Period and continuoing up to about 0.1 second Period where the PSa should be about 0.05 g. This is reasonable value considering that the PSa for a 0.4 seconds structure is 0.08 g. On the other hand, an increasing branch exists between the 0.4 seconds Period and the 1.0 second Period, and if the Period of the soil is about 2.0 seconds the increasing branch should continue up to that Period. Evidently, the problem is the corresponding value of the PSa.

Assuming that this ascending branch continues increasing with Period, at the same rate, a PSa of about 0.14 g. can be expected for the 2.0 seconds Period range. It should be noted that a larger acceleration in this period range would have induced some damage in the Induauto building. From this period, there should be a decreasing of the PSa values, so a straight line of equal velocity should be drawn which can not be limited due to the lack of records from past earthquakes.

CONCLUSIONS AND RECOMENDATIONS

An estimated spectral form of the 1980 Guayaquil earthquakes for a 5% damping, has been obtained through the 3D dynamic analysis of 2 buildings-that suffered damage during the event and of 1 building that did not suffer any type of damage.

The estimated spectra should not be taken quantitatively but qualitativaly, as to open a new point of view with respect to that of the E.C.(3) whose implicit design spectra is indicated in figure 13. The comparisson of the proposed spectra with that of the Code clearly indicates that, for a similar ground motion, rigid structures designed according to the code will be overdesigned, while flexible structures with periods larger than 0.9 seconds would be underdesigned. That is, the spectra suggested-by the code corresponds to stiff soil conditions while the proposed one aggrees with a soft type of soil. This situation has been demonstrated by Seed, et al. (8)

REFERENCES

1. National Observatory. Private Communication.
2. Espinoza, Alvaro. U.S.G.S. Scientist. Private Communication.
3. Ecuadorian Code. INEN-1978.
4. ETAB. Three Dimensional Analysis of building Systems. Extended Version. EERC report 1975.
5. INTERAC. A computer program to determine yield surfaces of R/C elements. Lara, Tola, Serrano, Consulting Engineers. 1978.
6. Sead, et al. "Relationships between maximum acceleration, maximum velocity, distance from source and local site conditions for moderately strong earthquakes. EERC report 75-17.

7. Nuques, J. Private Communication.

8. Seed, et al. "Site-dependt spectra for earthquake-resistant design" EERC Report 74-12.

TABLE 1

Periods of Vibration of the BEV building

Mode	Period (secs)	Direction
1	1.0	E-O
2	0.95	N-S
3	0.88	E-O
4	0.33	E-O
5	0.32	N-S
6	0.29	Rotational

TABLE 2

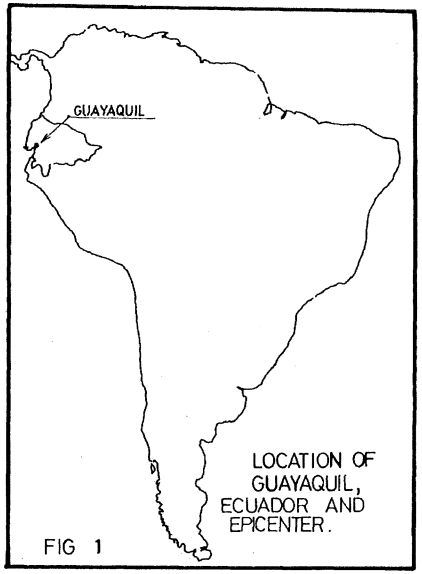
Vibration Periods of the Industrial building

Mode	Period (secs)	Direction
1	0.42	E-O + Rotation
2	0.37	N-J + Rotation
3	0.34	Rotational
4	0.26	E-O
5	0.23	N-S
6	0.23	N-S

TABLE 3

Vibration Periods of Induauto building

Mode	Period (secs)	Direction
1	2.4	NS
2	1.8	EW
3	1.6	NO
4	0.80	EW
5	0.68	EW
6	0.62	EW



LOCATION OF GUAYAQUIL, ECUADOR AND EPICENTER.

FIG 1

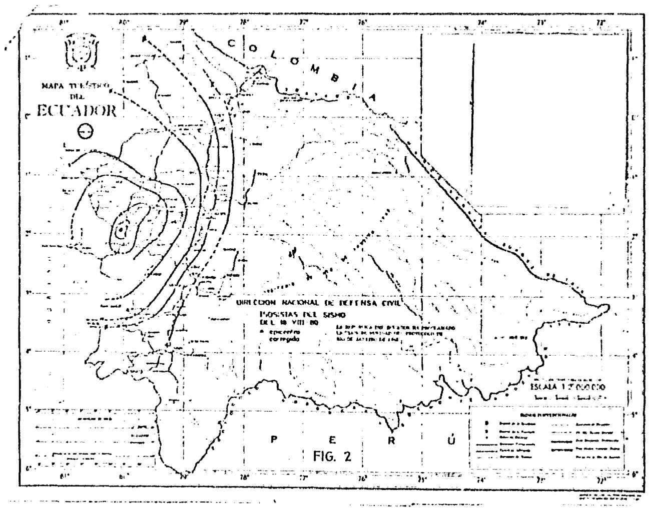
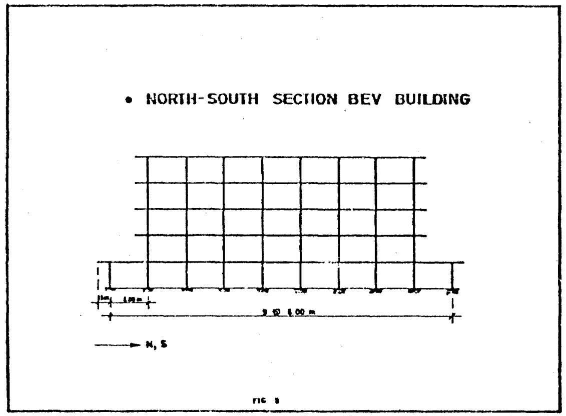


FIG. 2



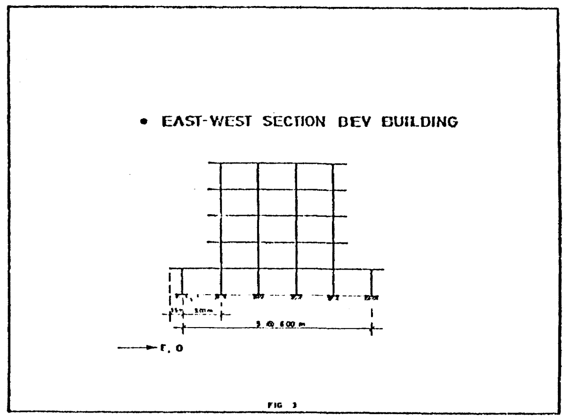


FIG 3

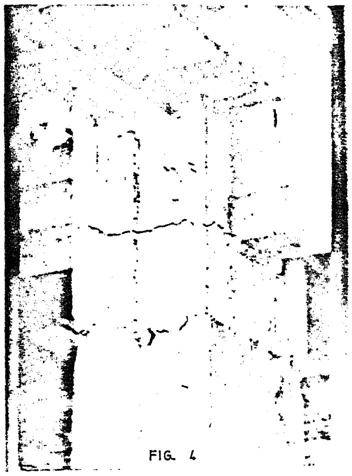


FIG. 4

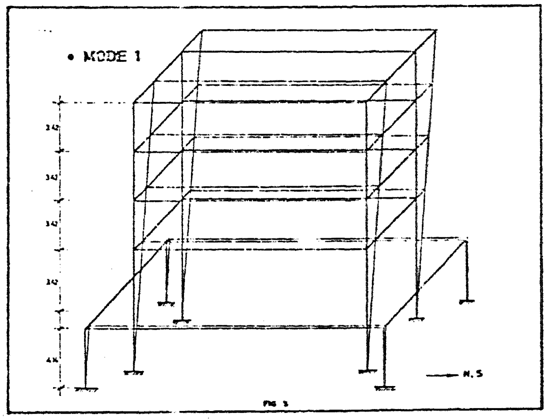


Fig. 5

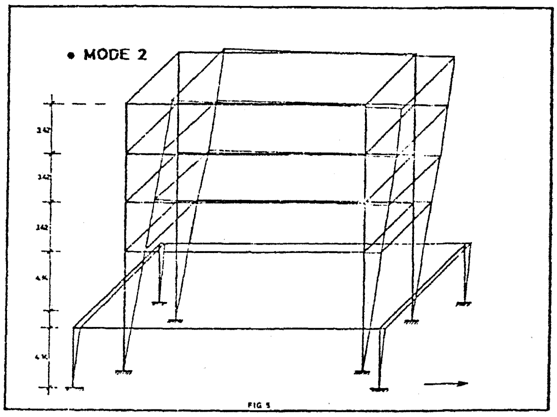


Fig. 5

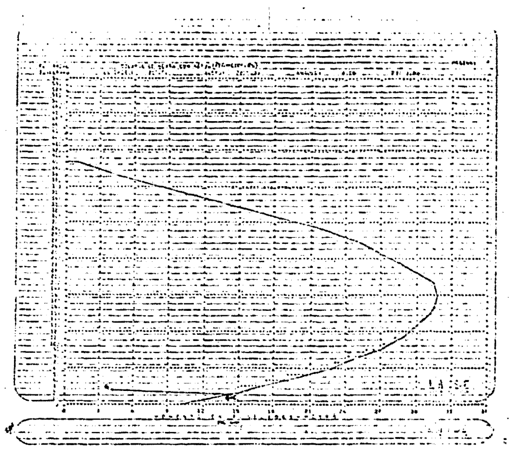


FIG. 6

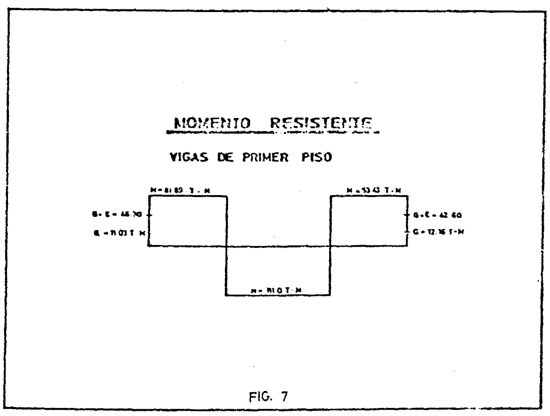


FIG. 7

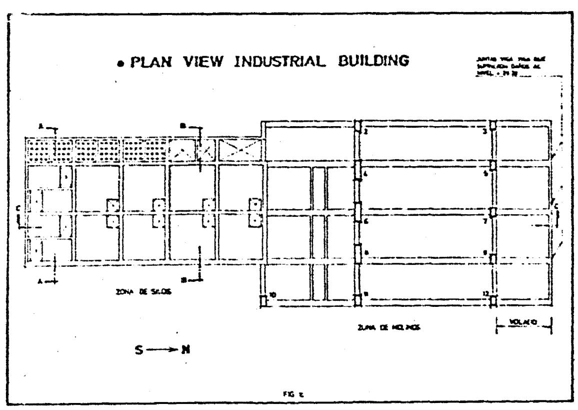
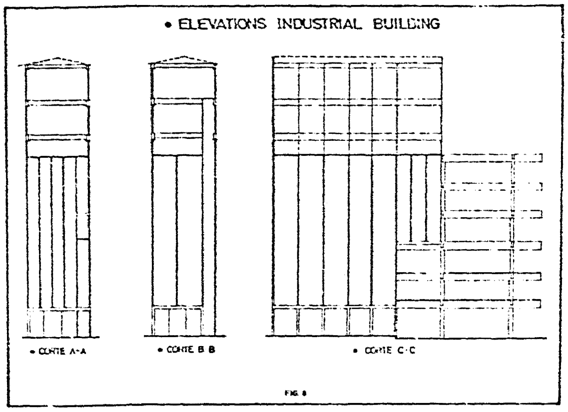
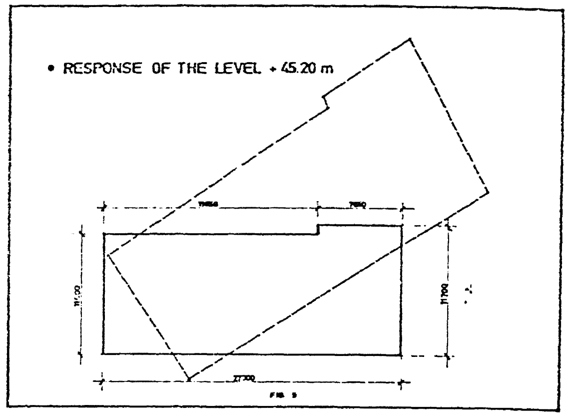
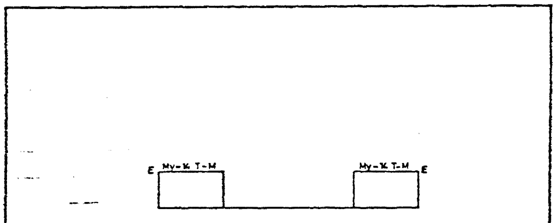


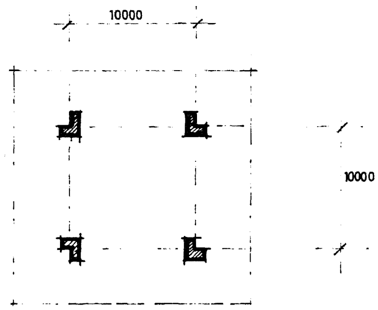
Fig. 8







• YIED SURFACE OF BEAMS AT LEVEL +45.20m.



• PLAN VIEW OF INDUAUTO BUILDING.

FIG. 11

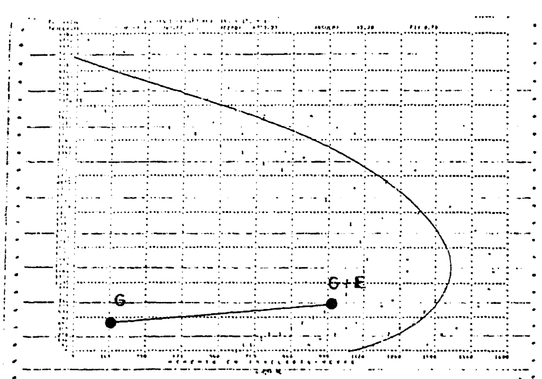
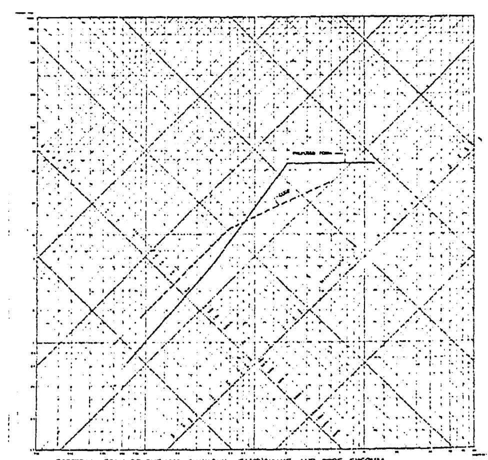


FIG. 12



• SPECTRAL FORM OF THE 1980 GUAYAQUIL EARTHQUAKE AND CODE SPECTRA FIG: 13